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DESIGN OF A WIDEBAND CIRCULARLY POLARIZED RFID READER ANTENNA

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Abstract

The main objective of this paper is to design a circularly polarized patch antenna with a very large bandwidth covering the UHF (ultra-high frequency) RFID band of 860 MHz - 928 MHz. The objective is to obtain an axial ratio (AR) lower than 3 dB and a return loss (RL) lower than -10 dB for the entire band of interest. The patch antenna design must also possess attributes such as high gain, high efficiency, ease of fabrication, low-cost fabrication and small form factor. The design consists of two stacked patch antennas with truncated corners and a square slot in the center. A coaxial cable is connected directly to the main patch, which is positioned in between the ground plane and the parasitic patch on top. The main patch also has an open circuit stub attached to it to improve impedance matching. A laborious design procedure, along with numerous parametric studies, were conducted using ANSYS HFSS in order to optimize the design.

- **Keywords: RFID UHF antenna design, circularly polarized antenna**

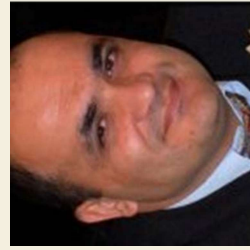
Biographies



Royalty Chihava graduated at the University of Nicosia in October 2019 and acquired a Bachelor of Science in Electrical Engineering with Summa Cum Laude. After his graduation he went on an IAESTE internship in the United Arab Emirates for 2 months where he was an electrical engineering intern studying the electrical system in Sajaa gas plant at Sharjah National Oil Corporation. He is interested in pursuing further studies in the area of RF and Microwave engineering and in participating in the discovery of future innovative applications in this technologically important field.



Dr Marios Nestoros is an Associate Professor at the Department of Engineering at the University of Nicosia. He received his BSc (1993) and PhD (2000) degrees in Physics from the University of Athens and University of Cyprus, respectively. From 1999-2002 he worked as a clinical medical physicist at the Bank of Cyprus Oncology Center. His research interests include: non-destructive material characterization with photothermal techniques, laser-matter interactions, semiconductor physics and applied electromagnetics. His latest publications in the field of applied electromagnetics are related to the design of liquid crystal based devices for mm-wave applications, such as phase shifters and their implementation in Beam-Steerable Arrays for 5G network, as well as the design and measurement of antennas for RFID applications.

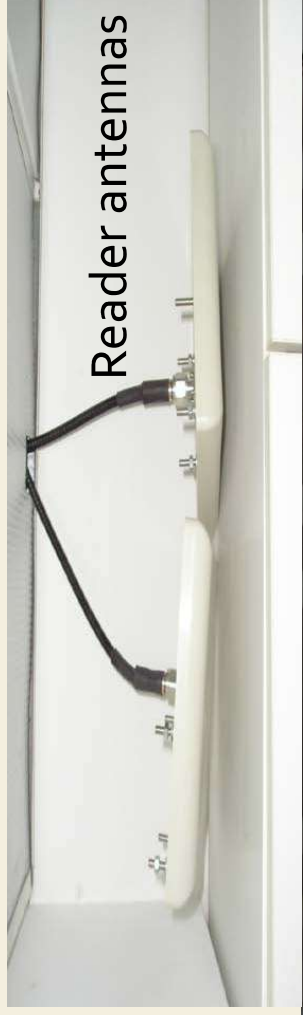


Dr Polycarpou is a Professor at the University of Nicosia in the Department of Engineering. He graduated from Arizona State University in 1992 earning a BSEE degree in Electrical Engineering with Summa Cum Laude. He continued his graduate studies at the same university where he received an MSc degree in Electrical Engineering in 1994 and a PhD degree in 1998. He has an extensive experience in funded research projects related to antenna analysis and design, microwave circuits and high-frequency electronic packaging, numerical methods in Electromagnetics, mode-matching and analytical methods, wave propagation in ferrites and liquid crystals, and radio frequency identification (RFID). He has worked on numerous projects funded by a number of private companies and non-profit organizations. He is the author of a book on the Introduction of the Finite Element Method (FEM) in Electromagnetics, two chapters in books on Antenna Theory and Numerical Methods, and more than 80 scientific papers in prestigious journals and refereed conference proceedings. He is a Senior Member of the Institute of Electrical and Electronics Engineering (IEEE), member of the IEEE AP and MTT Societies, and a reviewer of scientific articles published in PIERS, JEMWA, IEEE, AIP, APS, and IET magazines. He is also an Associate Editor of the IET Microwaves, Antennas & Propagation journal.

Introduction

A Radio Frequency Identification (RFID) system uses radio frequency waves to transfer information between the reader and the tag, which is attached to an object. The object could be anything ranging from books in a library, medicines in a pharmacy, boxes in a warehouse, items in a shop, animals (birds, livestock), people, and more. UHF RFID systems range from 850 MHz to 950 MHz and most countries all over the world have their operating frequencies within this bandwidth. For an effective RFID communication system, a high gain, wide bandwidth, circularly polarized reader antenna must be designed and fabricated in order to ensure sufficient reading range. In an attempt to improve axial ratio and impedance bandwidth, many antenna designs have been realized by other researchers.

RFID application for a healthcare system (pharmacy)



RFID tag was attached on an IV (liquid based)



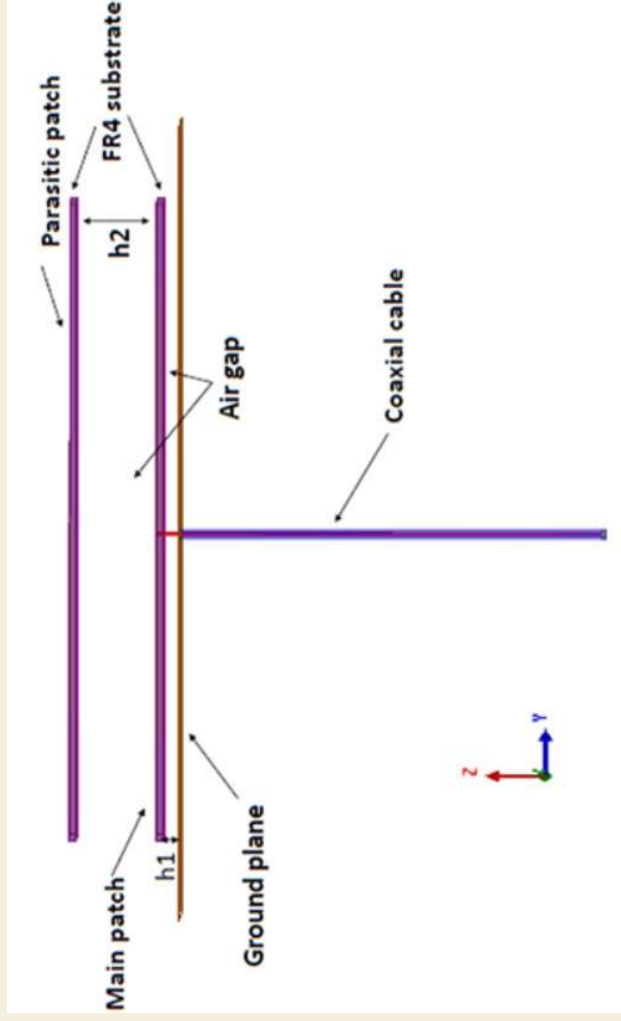
RFID tag attached on powder-based drugs

Introduction

In some of these designs, stacked patches with truncated corners were introduced in order to increase both impedance and axial ratio bandwidth. Use of stacked patches introduces additional resonant frequencies, thus enhancing impedance bandwidth. By truncating the corners of the patch, the axial ratio bandwidth can be improved although too much truncation results in a reduction in impedance bandwidth. The major challenge in the design procedure is to satisfy both constraints for the entire band of interest, which is not an easy process as there are always trade-offs in achieving an optimum design.

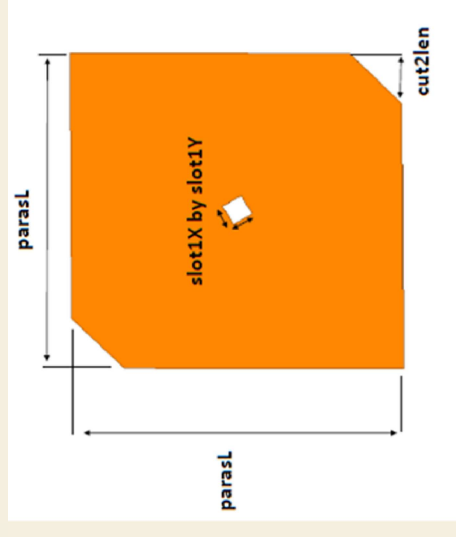
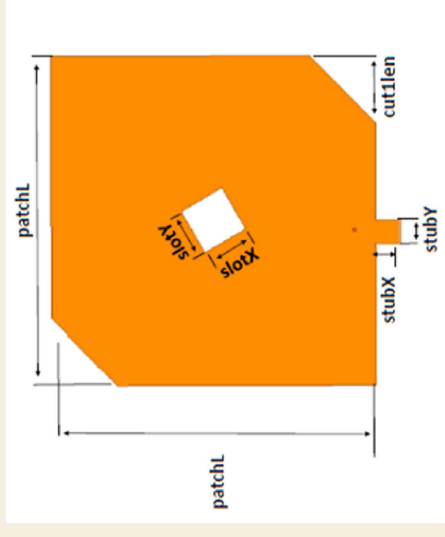
Antenna Design

The proposed antenna geometry consists of two stacked square patches, built on FR4 substrates, with truncated corners and an etched slot at the center. The two patches are separated by an air gap with height h_2 ; the FR4 substrate has a thickness equal to 1.6 mm. The main patch is connected to a 50-ohm coaxial probe, positioned at coordinates x_p and y_p with reference being the center of the patch, and is separated from the ground plane by an air gap with height h_1 .



Antenna Design

The two microstrip patches have the two opposite corners truncated in order to create the excitation of two orthogonal modes with phase quadrature. The design is characterized by an etched slot, rotated by 30° degrees with respect to the principal axis, at the center of each of the two patches in order to further improve the axial ratio (AR) bandwidth. The main patch also has an open-circuit stub close to the probe feed in order to enhance impedance bandwidth. The spacing between the two patches is achieved through nylon posts fixed at the four corners of the FR₄ substrate.



Parametric Studies

The initial design dimensions related to the width and length of the microstrip patches were calculated from the well-known equations presented in Balanis' book on Antenna theory: Analysis and design, by John Wiley & Sons, 2016. A series of parametric studies was carried out in order to allow an understanding of how the design parameters affect the figures of merit of the antenna and help us achieve the optimum design.

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + \frac{12h}{W} \right)^{-1/2}$$

f_r	desired resonating frequency
W	Patch width
L	Patch length
h	Substrate height
ϵ_r	relative dielectric constant of the substrate
ϵ_{reff}	effective relative dielectric constant of the substrate
c	Speed of light
ΔL	change in length due to fringing effects

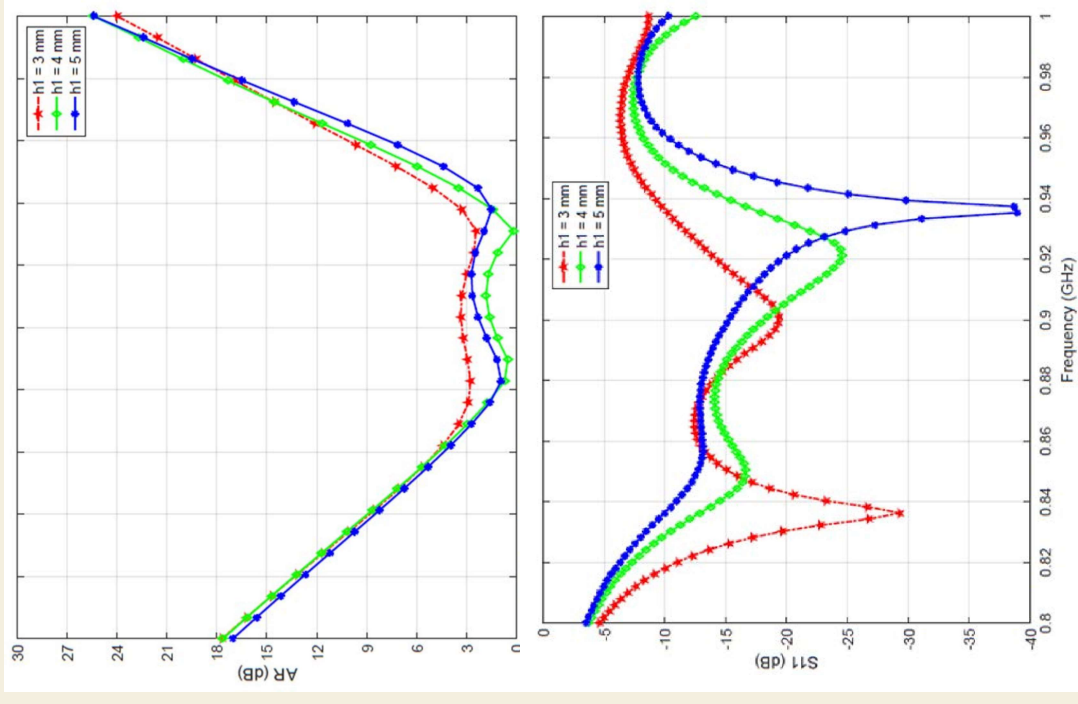
$$W = \frac{c}{2f_r} \sqrt{\frac{2}{\epsilon_r + 1}}$$

$$L = \frac{c}{2f_r \sqrt{\epsilon_{reff}}} - 2\Delta L$$

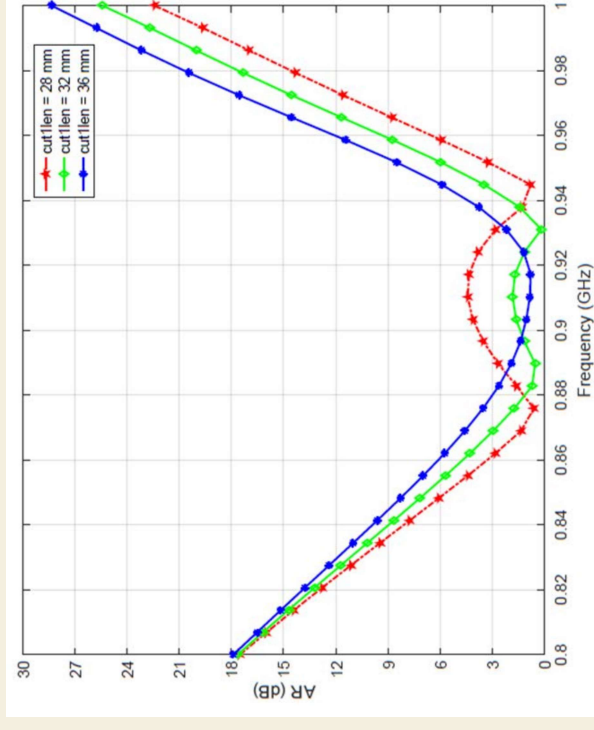
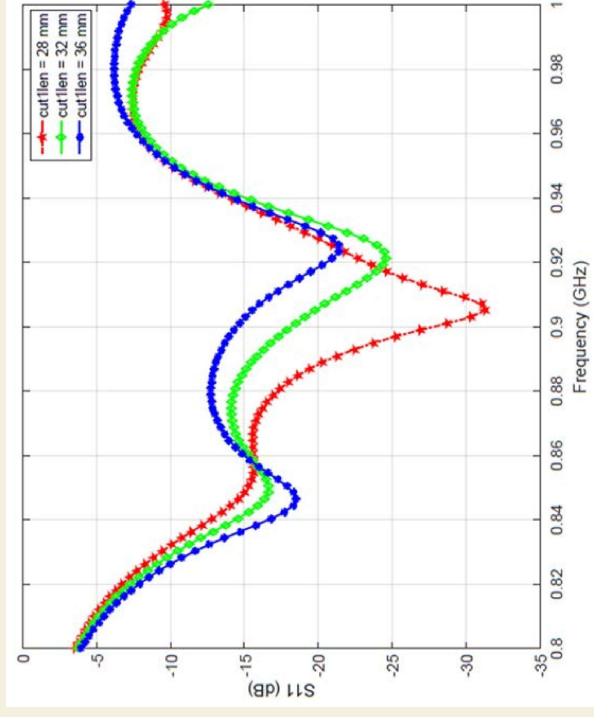
$$\Delta L = 0.412h \frac{(\epsilon_{reff} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{reff} - 0.258) \left(\frac{W}{h} + 0.8 \right)}$$

Height of the main patch

The corresponding S_{11} is affected significantly by the change in the height of the main patch. As depicted below, the height parameter h_1 may favor one of the bands over the other. Even a slight increase in the height shifts the S_{11} to the higher end of the band. The choice of h_1 equal to 4 mm provides an acceptable S_{11} for the entire UHF EU/FCC band allocated for RFID applications.

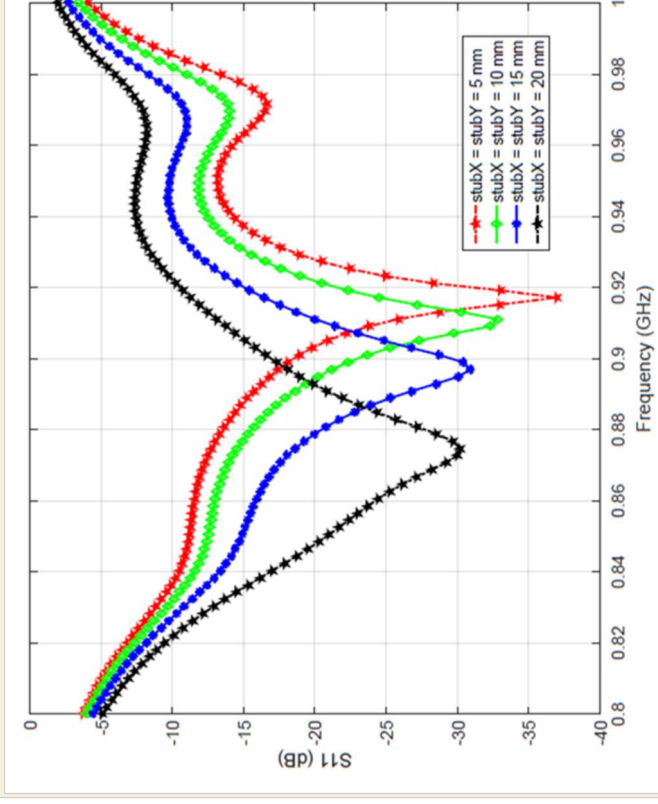
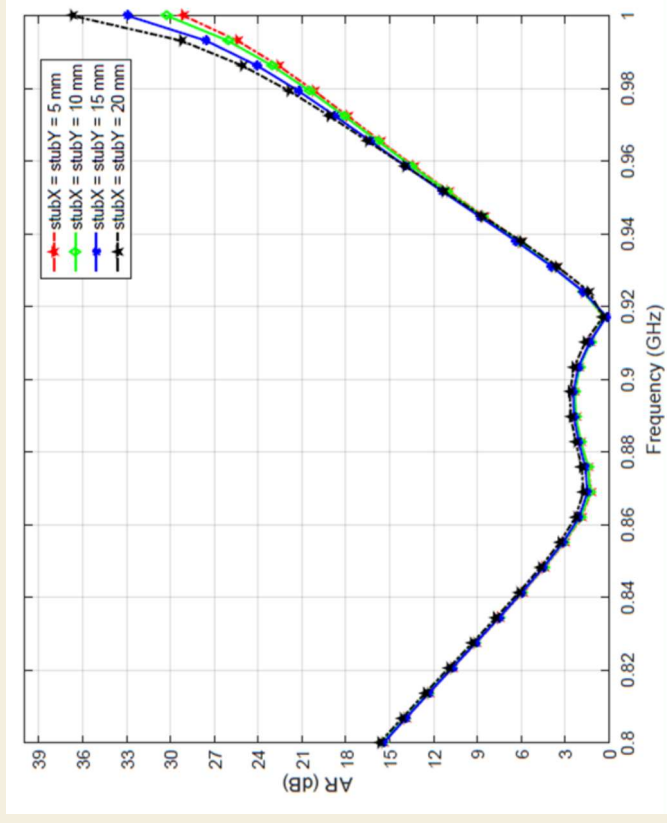


Corner truncation of the main patch



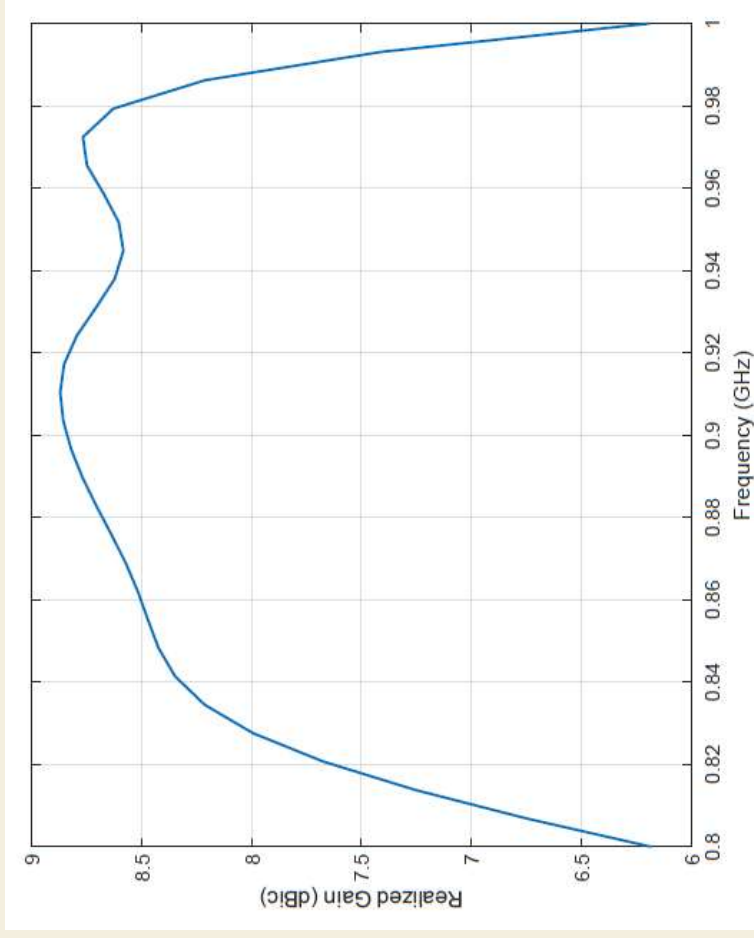
By increasing the size of corner truncation of the main patch (cut₁len), the AR worsens at the two ends of the UHF RFID band (850 – 880 MHz & 930 – 950 MHz) and improves in the middle. The S_{11} improves as the corner truncation length decreases from 36 mm to 28 mm. This, however, represents a trade-off between S_{11} and AR because any improvement in S_{11} results in degradation of the AR, as seen above.

Open-circuit stub



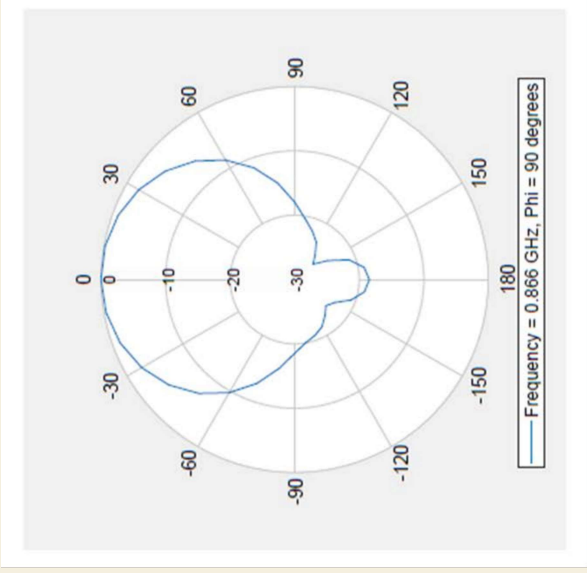
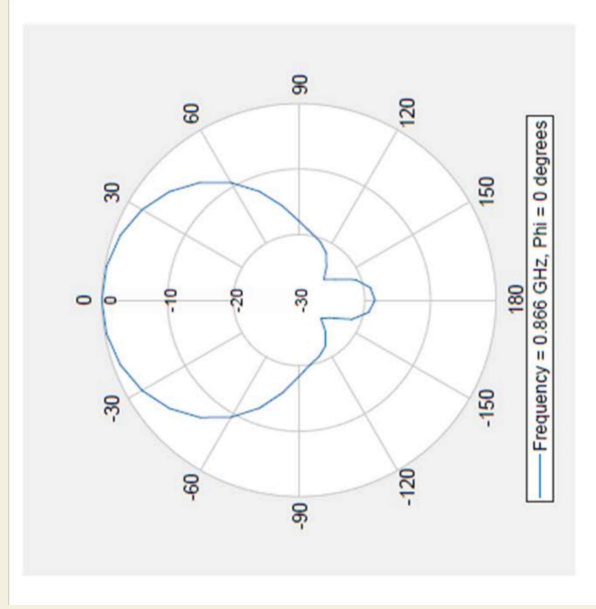
The addition of a stub at the edge of the main stub enhances the impedance matching and helps covering a wider frequency band between 830 and 982 MHz, as illustrated in the figure above. The addition of the stub barely affects the AR.

Antenna realized gain



The proposed antenna has a realized gain of approximately 8.8 dBi, which is considered sufficient, given that the stacked microstrip patches were built on lossy FR4 substrates.

Radiation Patterns



As illustrated, the two elevation radiation patterns at 900 MHz, which correspond to the x-z and y-z planes, resemble typical patch antenna patterns radiating in the broadside direction.

Important Concluding remarks

A circularly polarized RFID antenna on FR4 substrates that operates well in both the EU and FCC frequency bands was designed and optimized. A series of parametric studies using ANSYS HFSS was conducted in order to reach an optimum design (see Table on the right) . This design, which consists of stacked patches with truncated corners and slots/stub, is characterized by a maximum realized gain equal to 8.8 dBi and an impedance bandwidth ranging between 830 MHz and 982 MHz.

	Main	Parasitic
L (mm) x W(mm)	138X138	120 X120
h1(mm)	4	-
h2(mm)	-	19
Cut1len (mm)-square	28	-
Cut2len (mm)-square	-	19
Stub size (x,y)		
Slot size (mm x mm)	20x20	8x8
Slot rotation	30°	30°

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